Recycling Tevatron Pbars: efficiency estimate update

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Intro in History of R-ing

- **TM-1991 (1996) "Recycler TDR"**

Table 2.1.2: Parameters which describe the effect of recycling antiprotons on antiproton stacking and average luminosity during Run II. Comparisons are made with Run I operations (without both the Main Injector and the Recycler).

Parameter	Run I	MI only	Recycler
Store Duration T_s (hr)	12	12	7
Injection Time T_f (hr)	2.5	1	1
Antiprotons at End of Store	73%	65%	78%
Deceleration Efficiency	0%	0%	80%
Acceleration Efficiency	75%	90%	90%
Integrated Luminosity (pb^{-1}/store)	0.56	2.9	3.4
Required Usable Stack (10^{10})	48	144	264
Antiprotons Recycled (10^{10})	0	0	148
New Antiprotons Stacked (10^{10})	48	144	116
Required Stacking Rate (10^{10}/hr)	4	12	17
Average Luminosity (pb-1/hr)	0.04	0.21	0.43
Store Hours Needed to Achieve the Snowmass Criterion Between Integrated and Peak Luminosity	98 (typical)	101	93

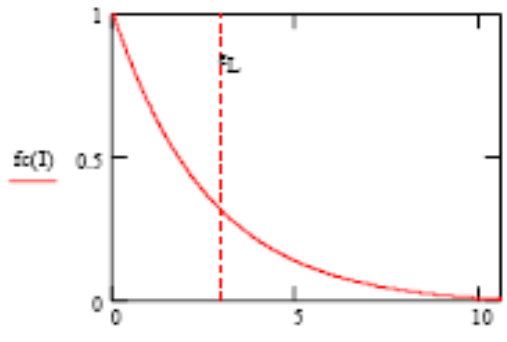
- **logistics of recycling presented**
- **7hr stores, 10% stores lost, est effect ~2x*L***

Abandoning R-ing (2003)

- **AAC and DoE Reviews (V.Lebedev)**
  - **based on detailed model, compared to 2002 experience**

Efficiency of the Antiproton Recycling

Transverse efficiency into 30 mm mrad acceptance, κ_{tr}	0.969
Longitudinal efficiency into 3 eV s acceptance, κ_L	0.727
Fraction of stores with successfully decelerated protons, $\kappa_{success}$	0.7
Fraction of antiprotons survived at the store end, κ_{Tev}	0.747
Total efficiency of pbar recycling, $\kappa_{Tev}\,\kappa_{success}\,\kappa_L\,\kappa_{tr}$	**0.368**



Dependence of the longitudinal distribution function on the action at the end of a store

  - **was considered to be "not worthy":**

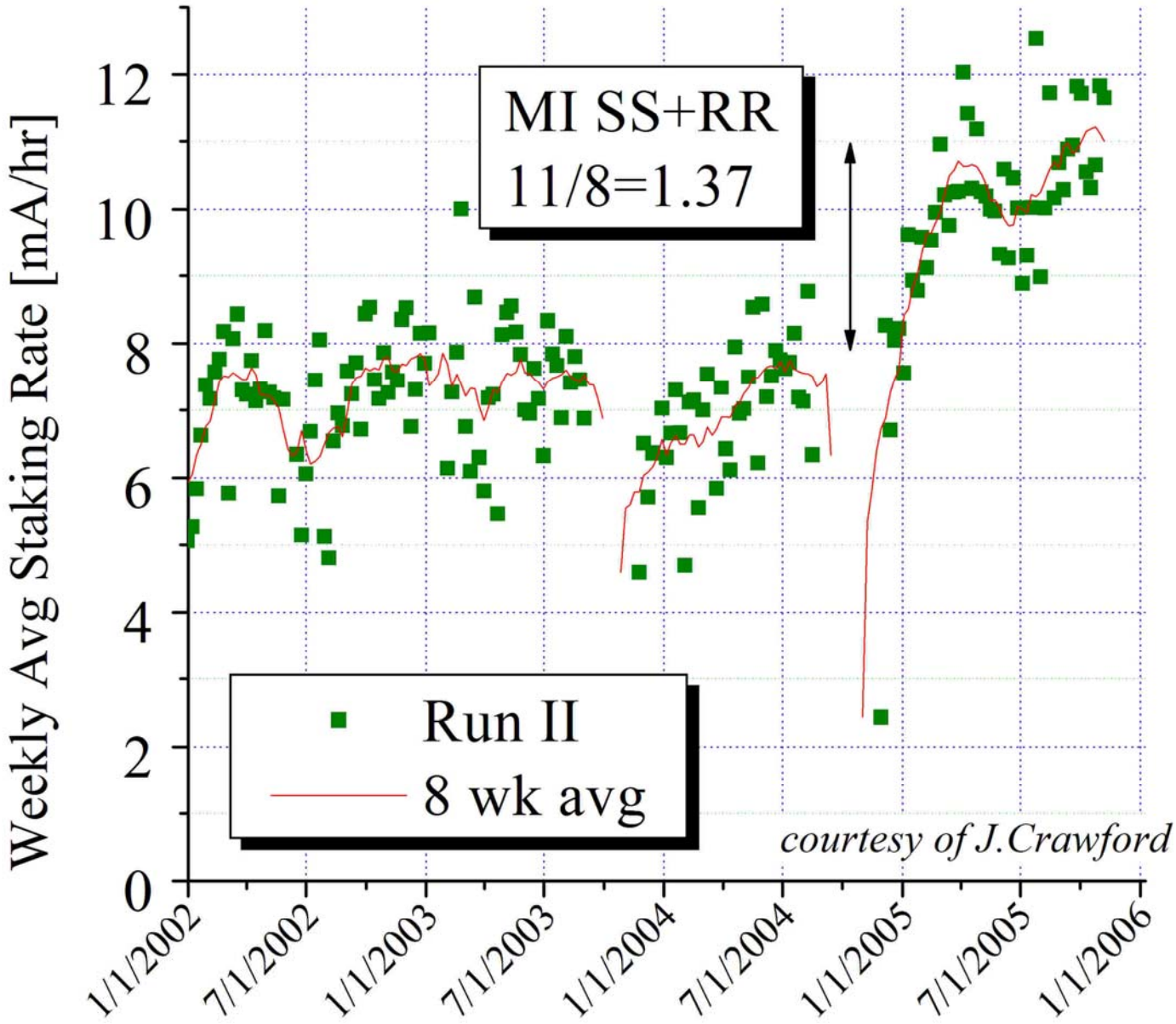
The major technical obstacle to recycling is the removal of the protons prior to antiproton deceleration and extraction. This must be accomplished quickly (so as not to significantly add to shot setup time) and reliably, without risking Tevatron quenches or significant radiation dose for the experiment detectors. Initial studies have indicated that meeting these requirements is problematic, and would require substantial work and study time.

It has been decided that no work will be scheduled for recycling at this time. The

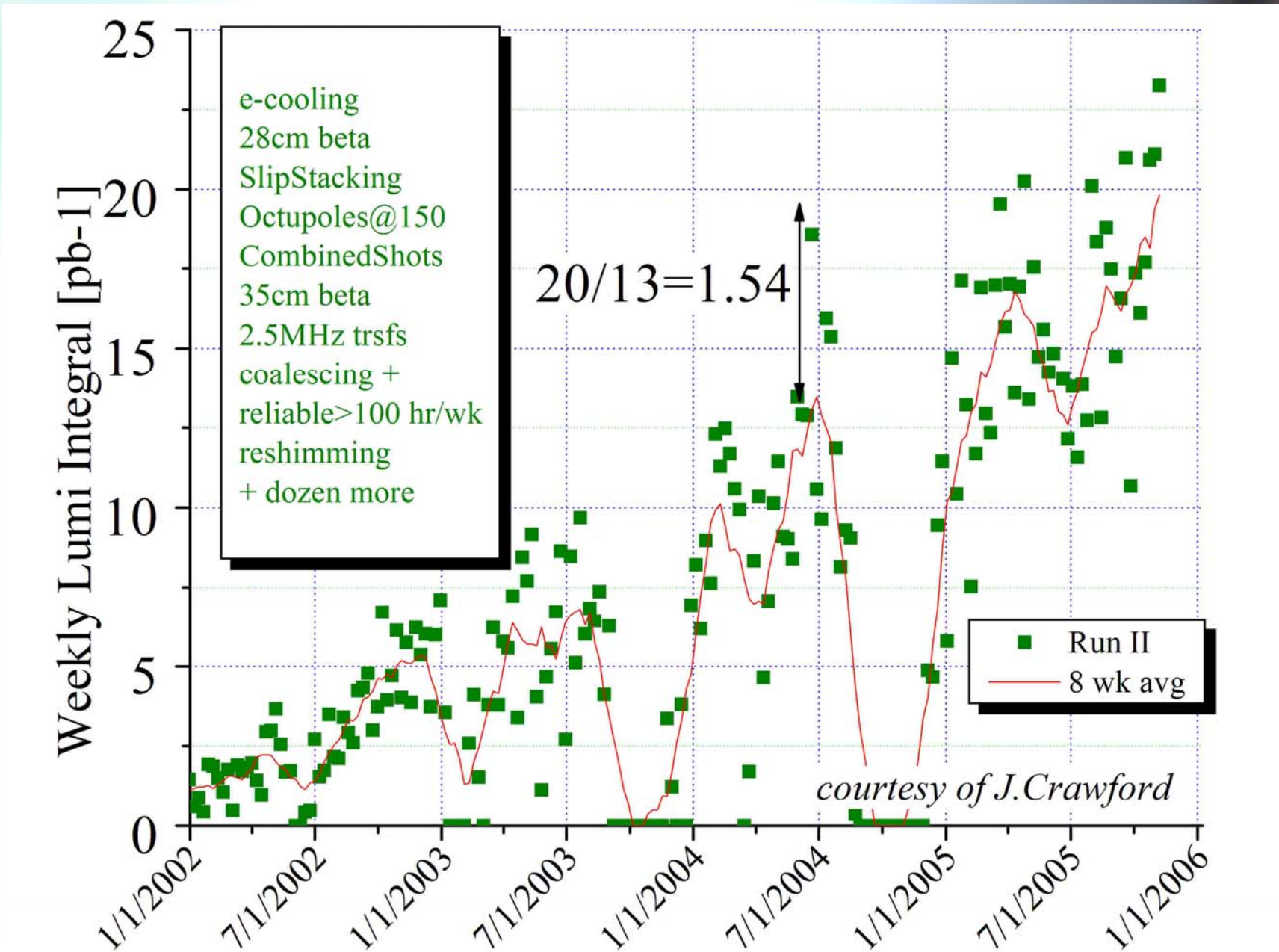
Resurrecting R-ing (2005)

- **have things changed?**
  - **Valery's analysis redone by VS and ~confirmed**
  - **reliability is up compared to 2002**
  - **instead of beam dynamics models, data from HEP stores used (e.g no tails in f(I) found)**
  - **total r-ing efficiency ~30% is product of :**
    - **transverse acceptance 0.96→0.9**
    - **% stores survive 0.7 → 0.8**
    - **3eVs acceptance 0.73 → 0.85**
    - **fraction Na left 0.75 → 0.50**
  - **gain of 15-25% is "worthy" nowdays:**
    - **"pbar thirst" stronger: no 45mA/hr goal anymore**
    - **pbar production rate is in focus of Run II upgrades**
    - **progress is not as fast as expected**

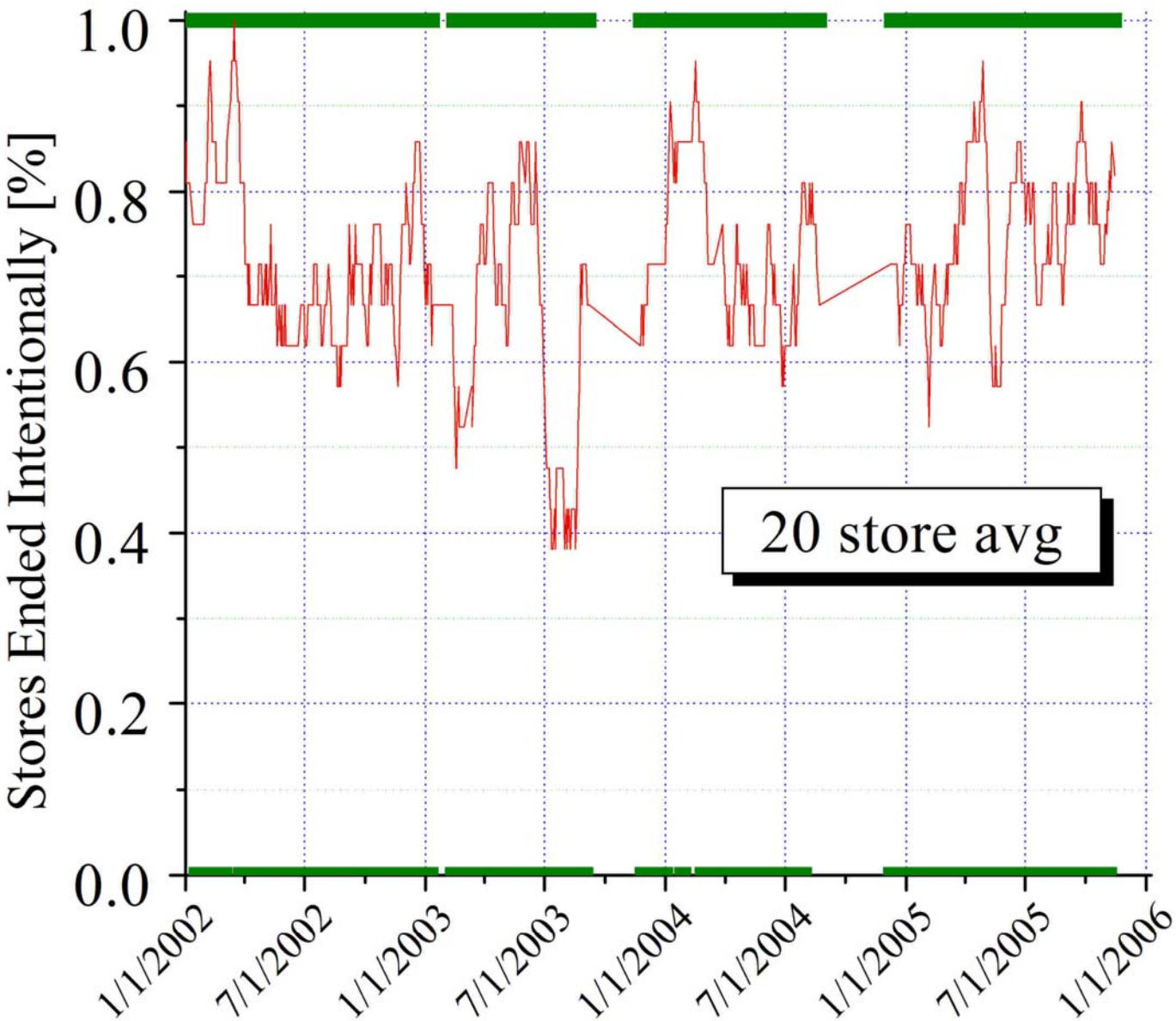
Run II Pbar Production 2002-05



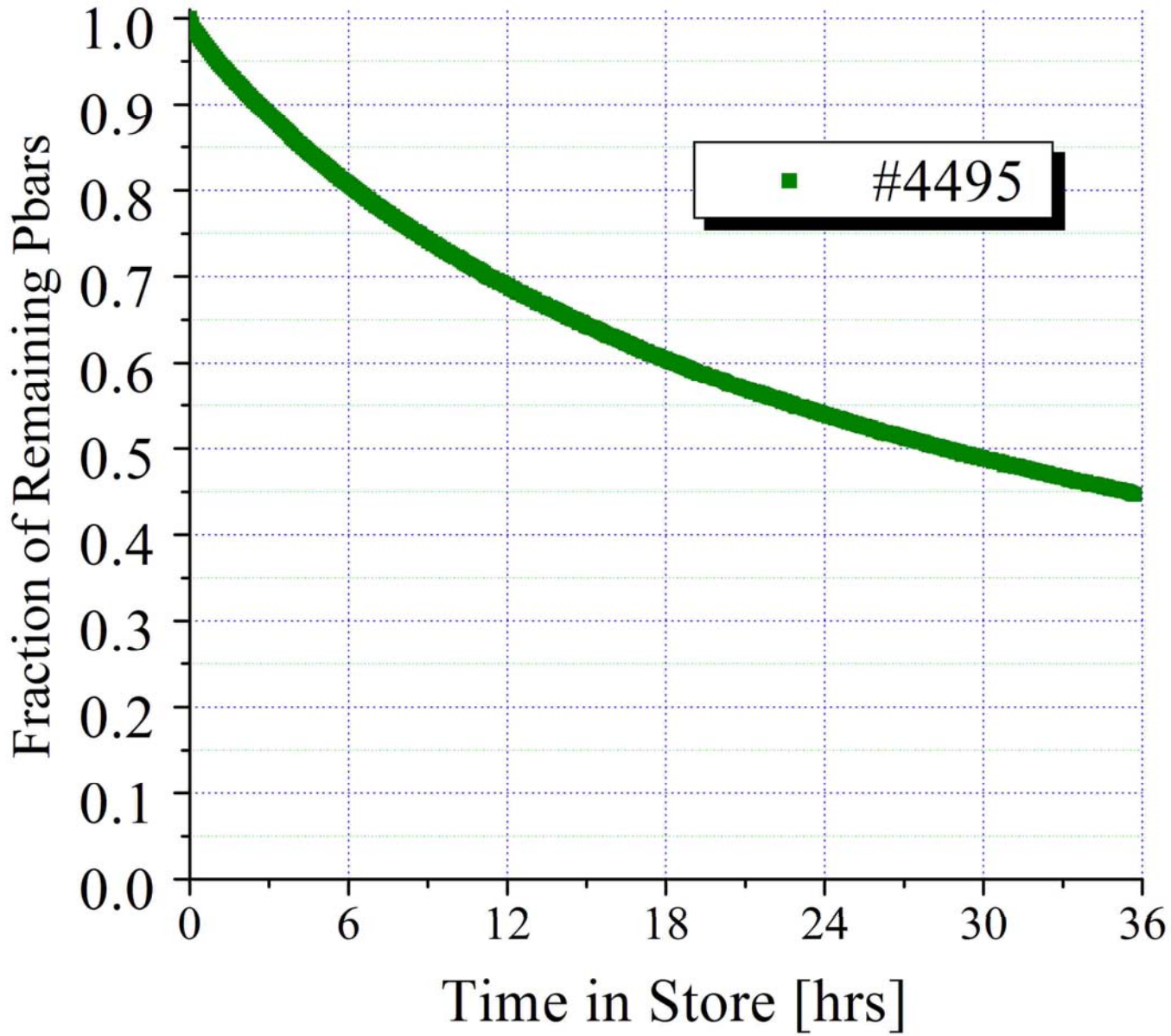
...and Integrated Luminosity



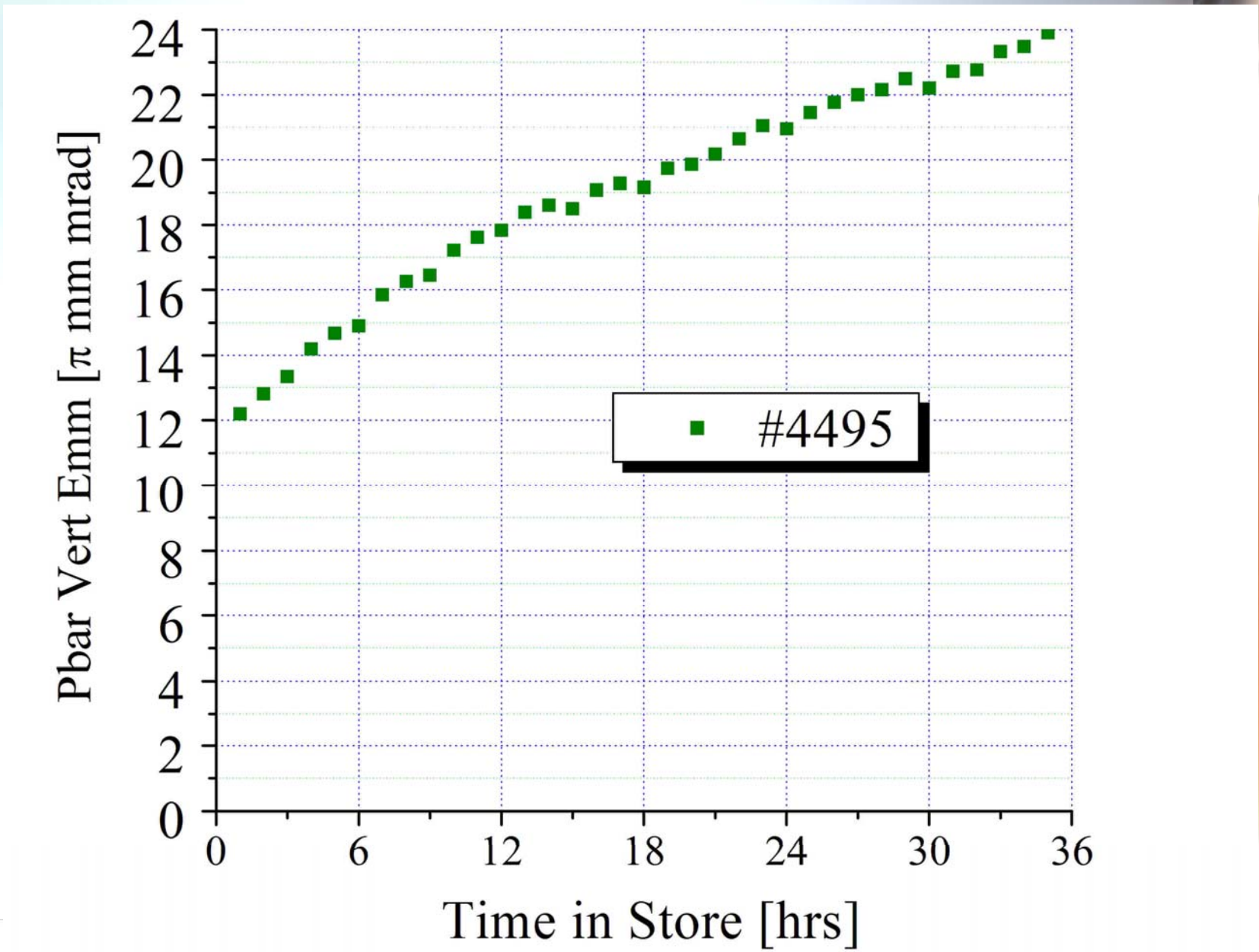
Store Ending 2002-05



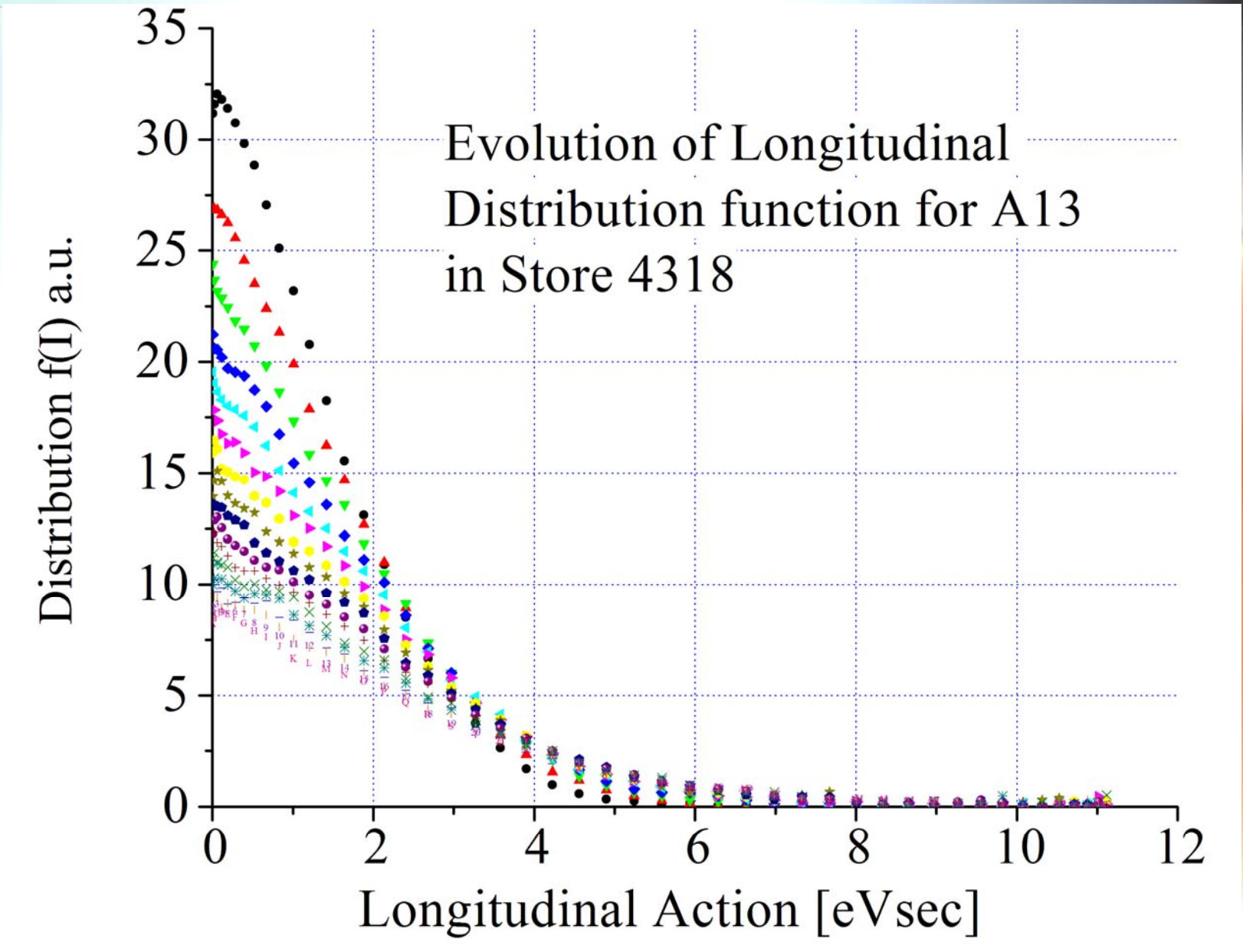
Pbar Intensity in the Tevatron



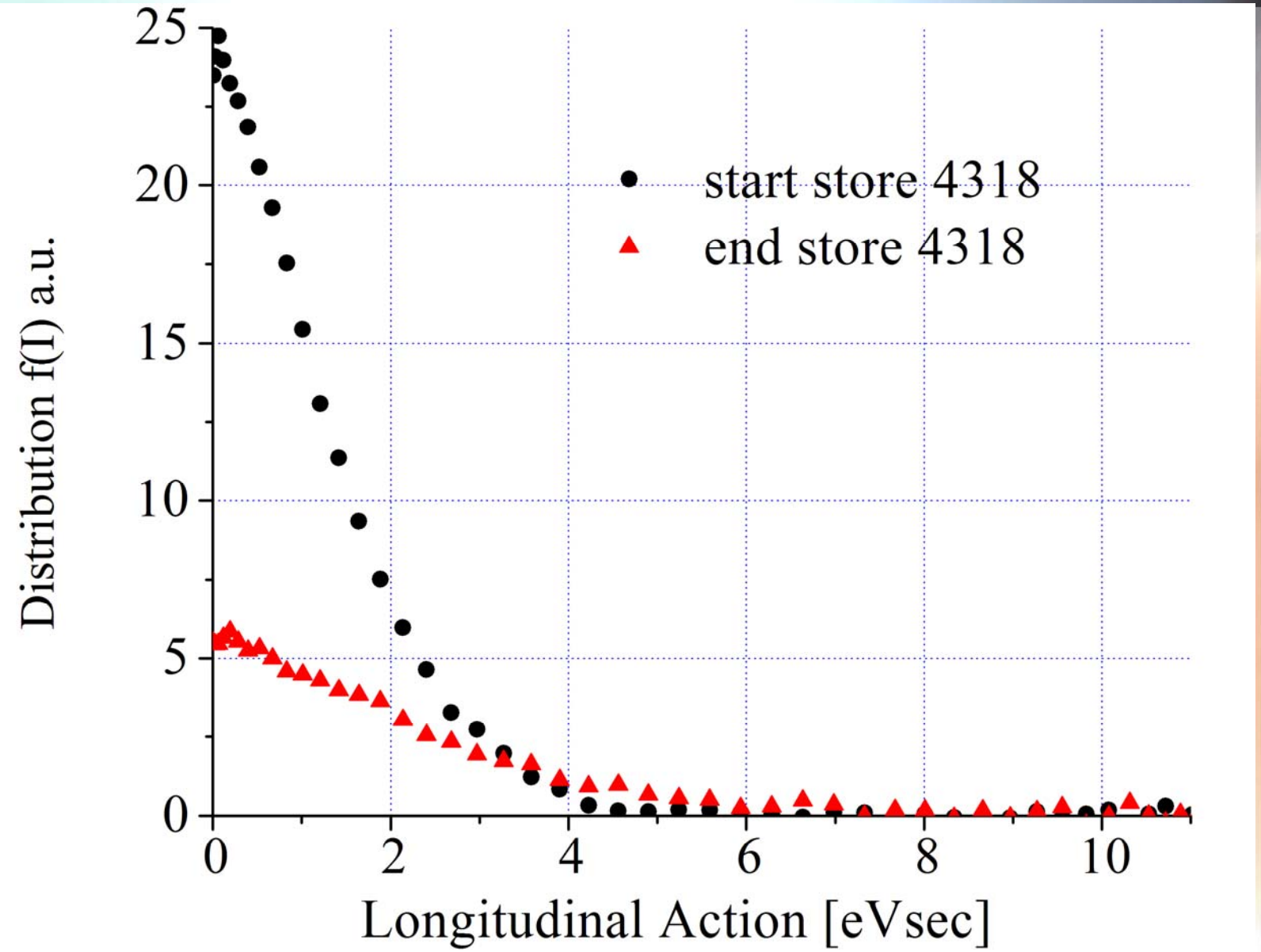
Pbar Emittances in Store



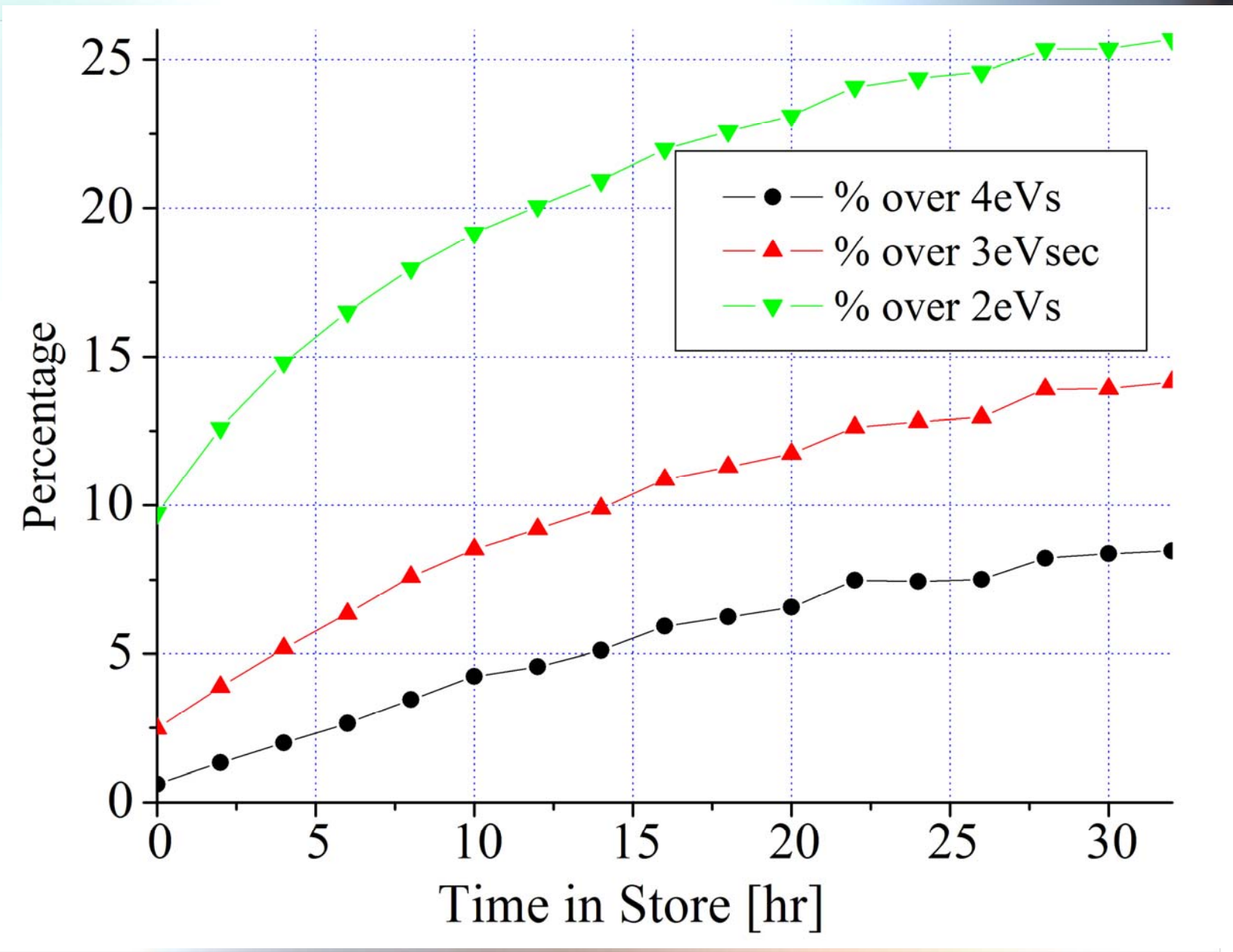
Pbars in the Tevatron: Evolution



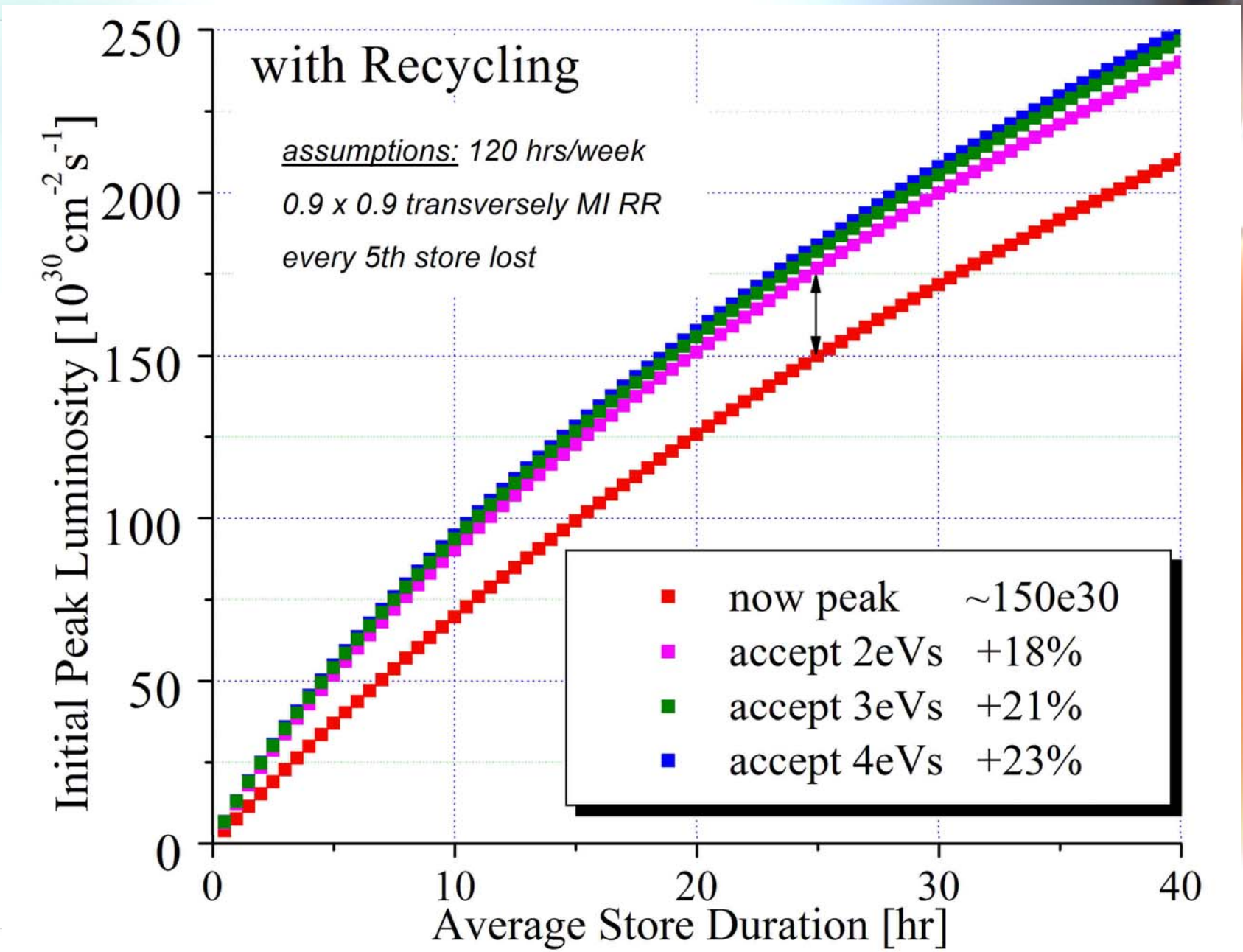
Pbars in the Tevatron: EoS vs SoS



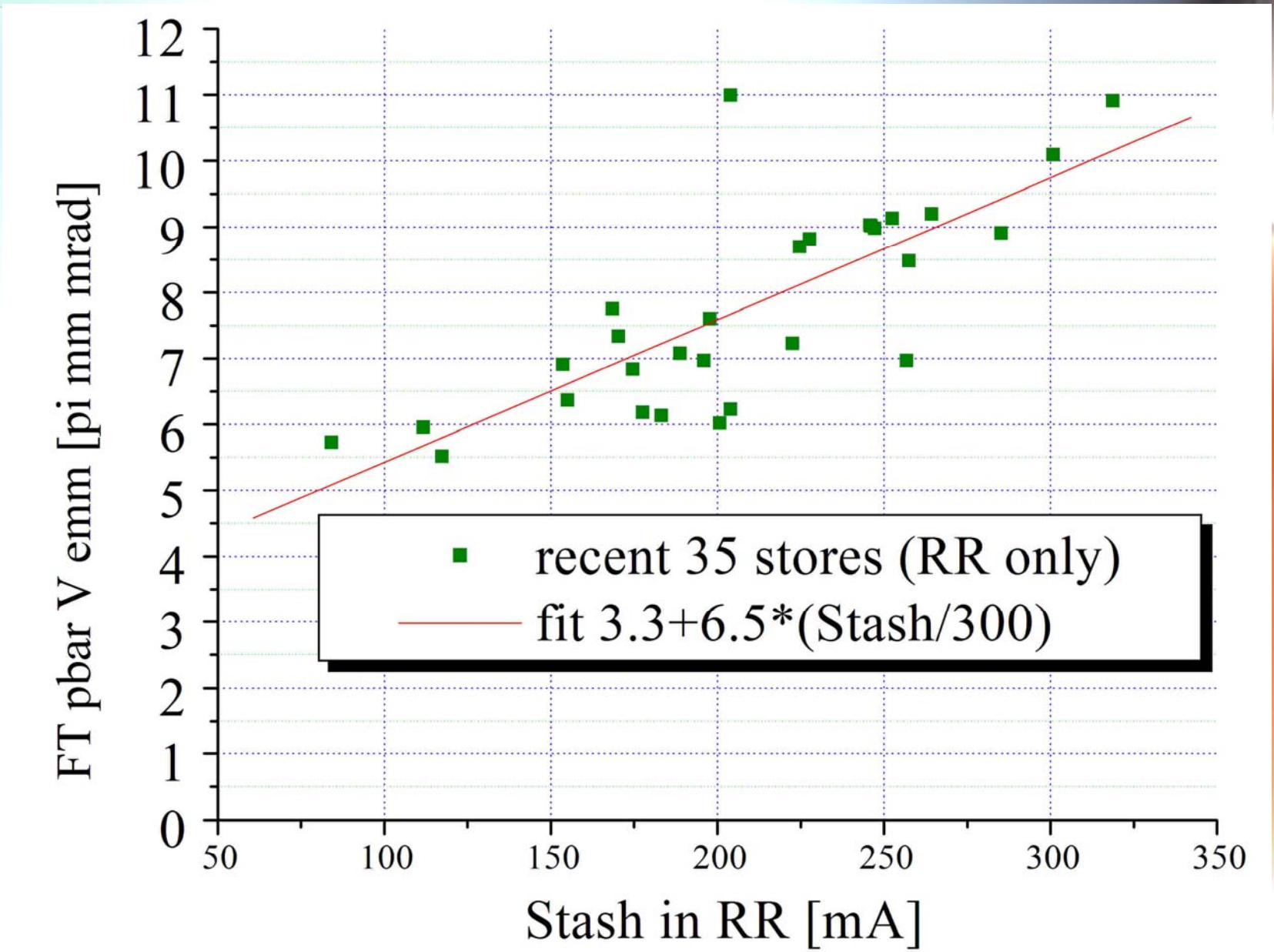
Pbars beyond acceptance in #4318



Gain in Peak Luminosity



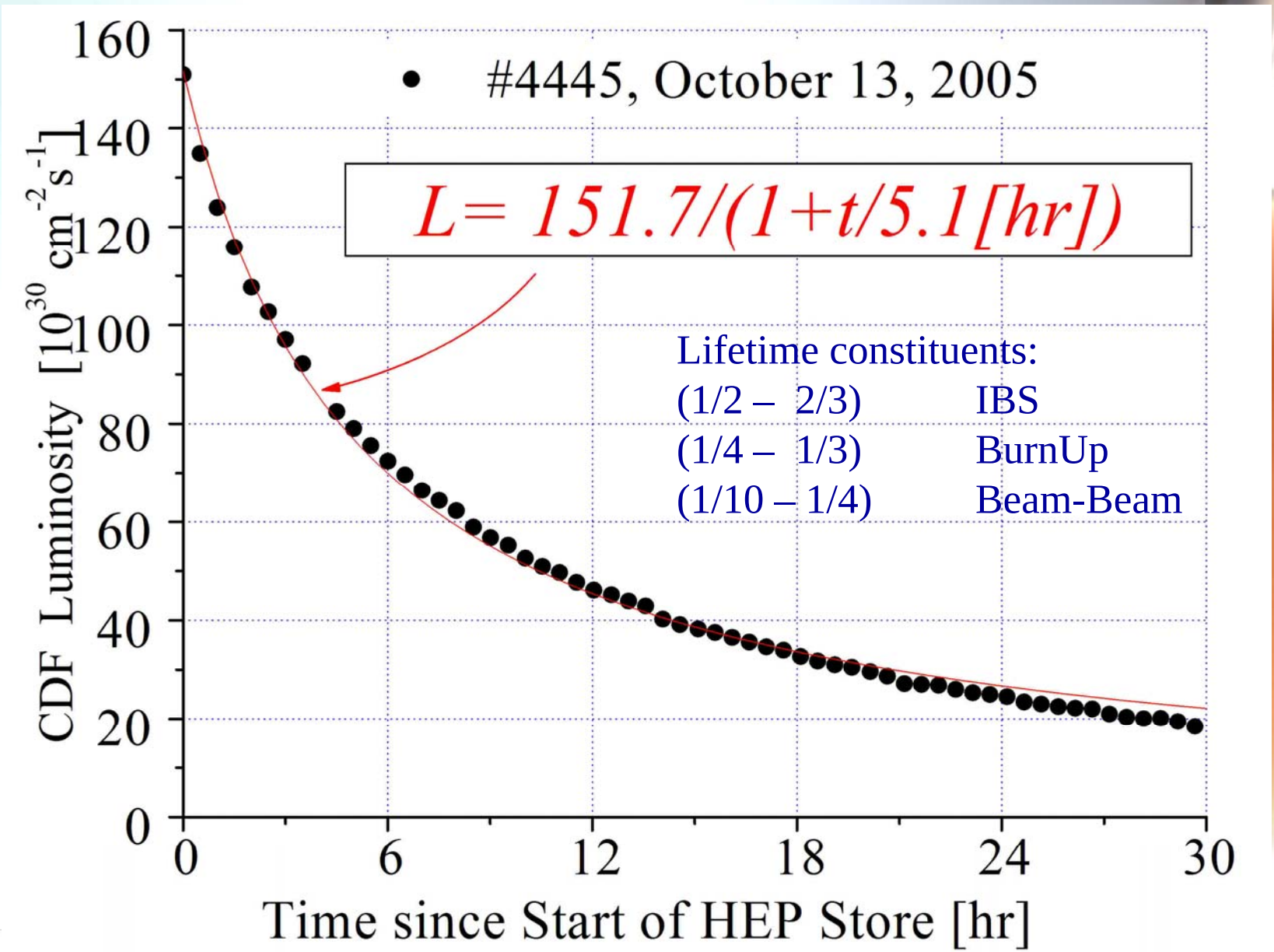
Larger Emittances take some toll..



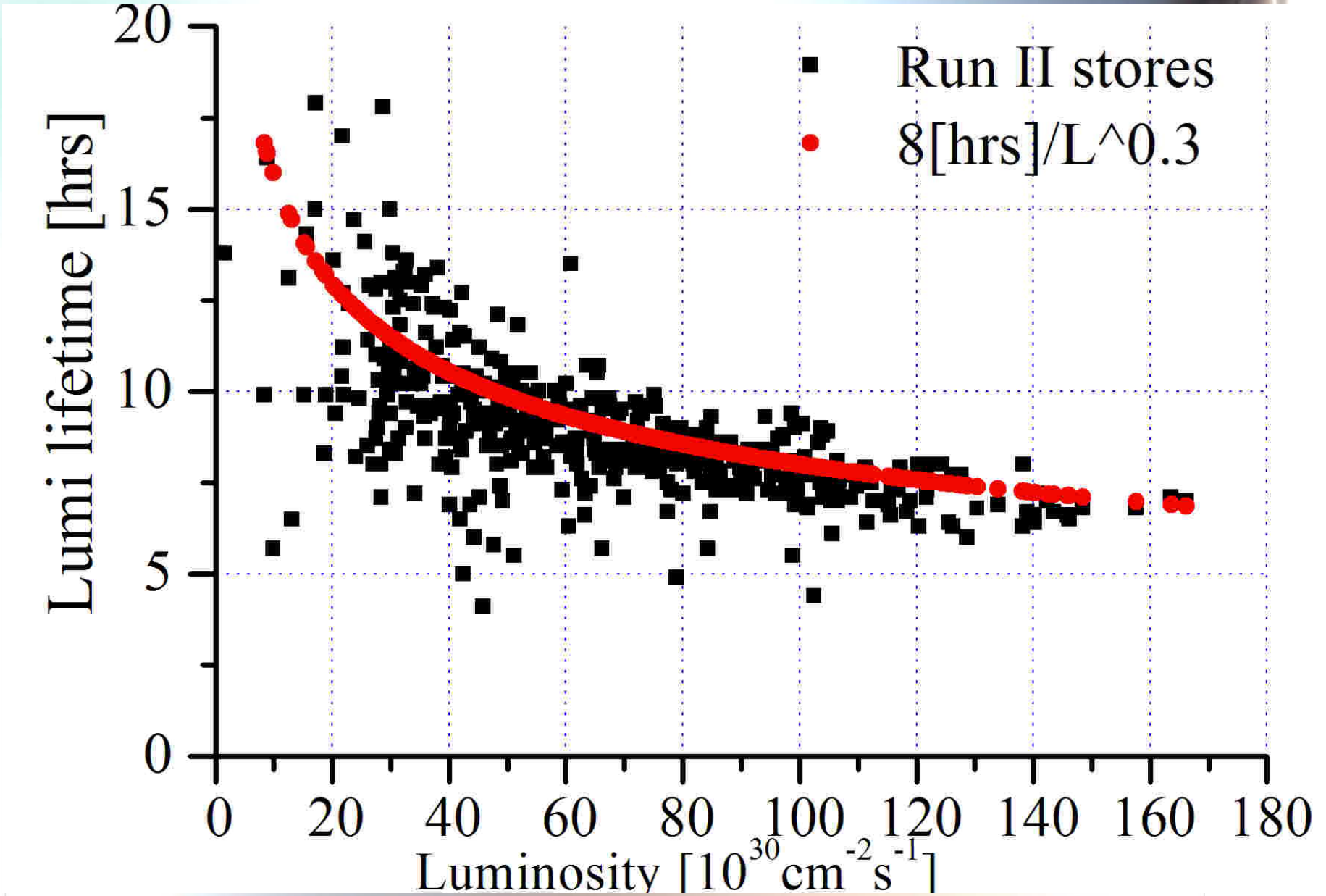
Luminosity Integral

- **Integral depends on:**
  - **peak luminosity**
  - **store duration**
  - **luminosity lifetime**
  - **# hrs/week (reliability)**

Luminosity Decays ~ 1/(1+Time/τ)

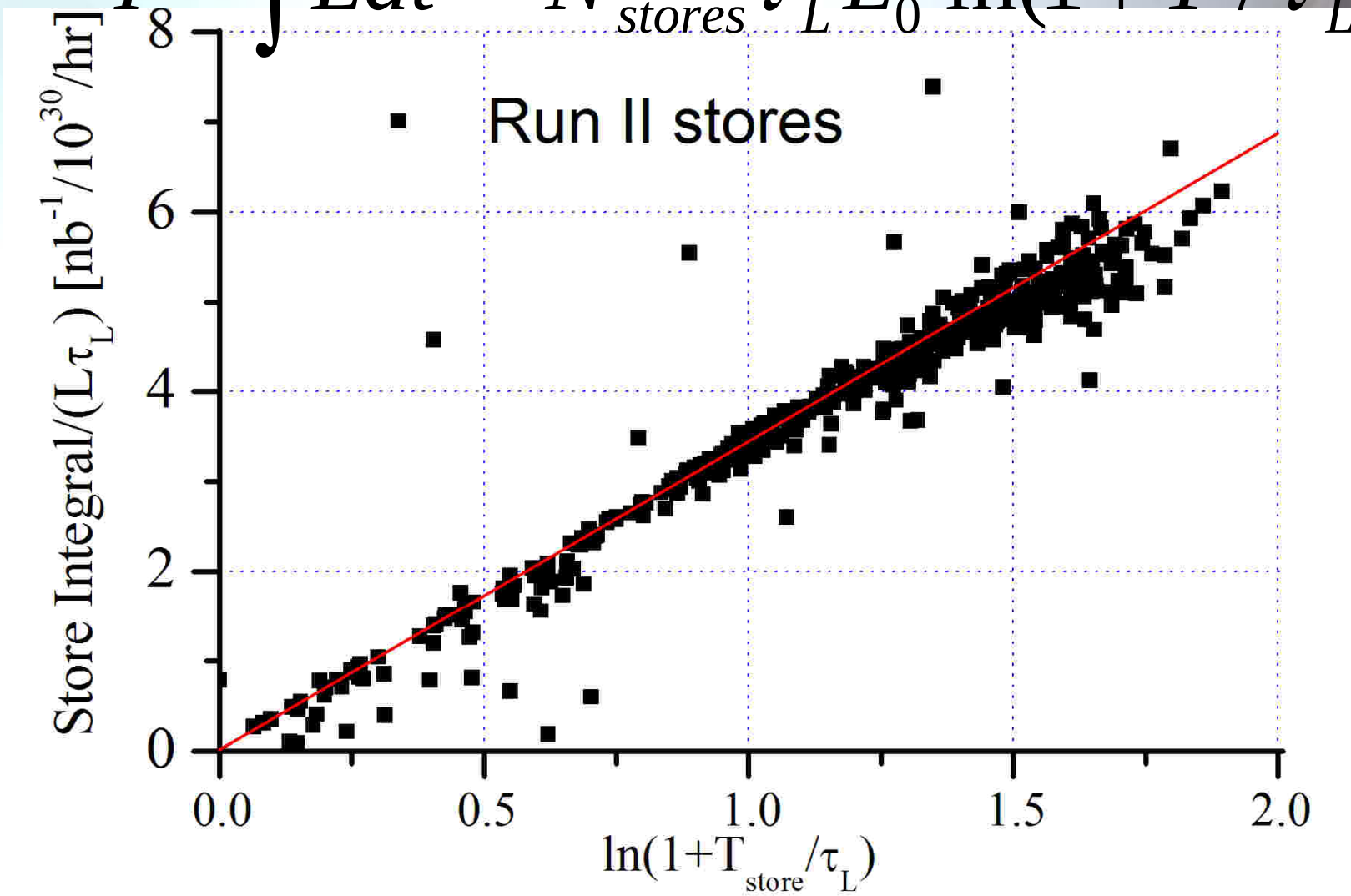


Luminosity Lifetime vs Peak Lumi

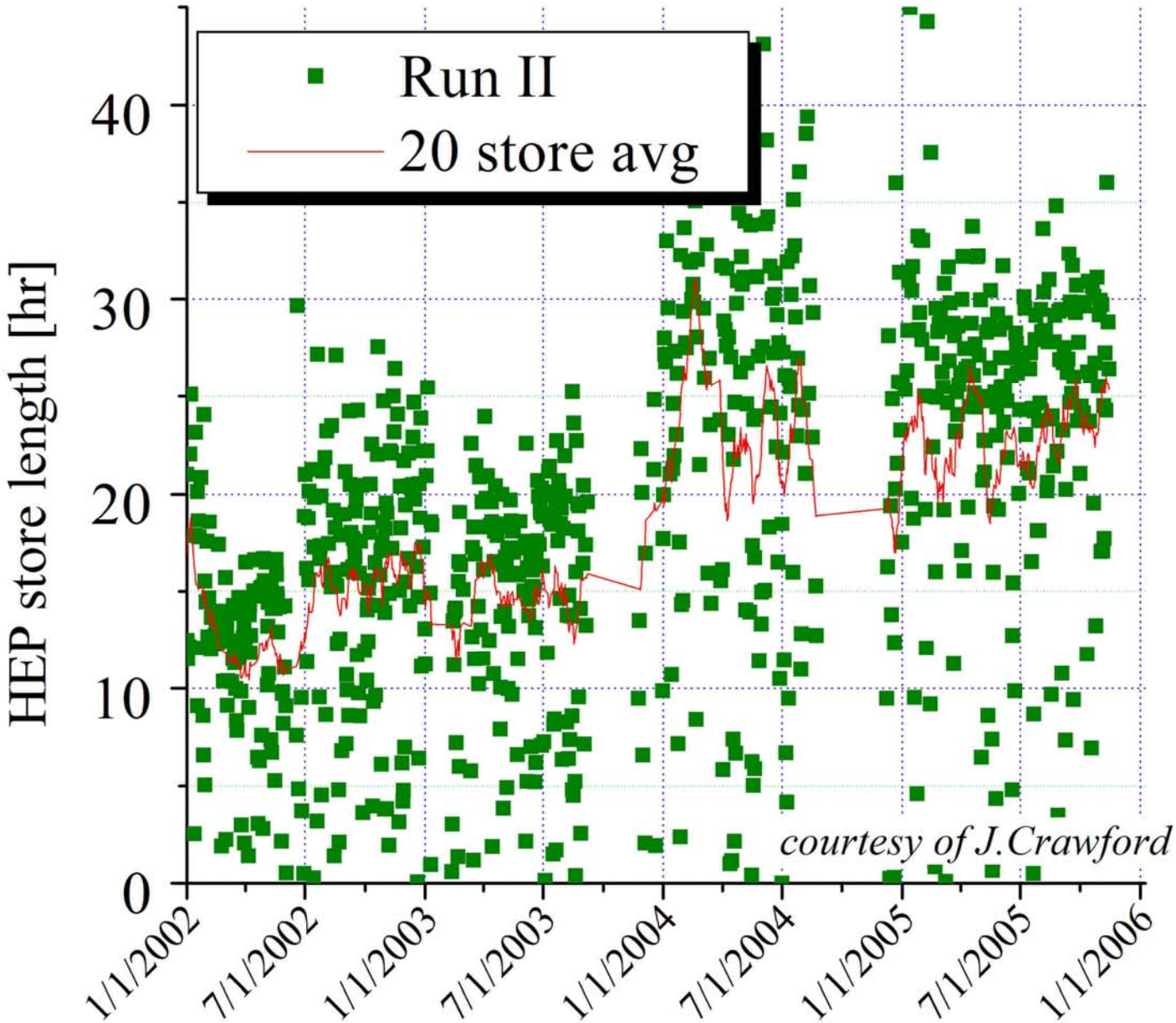


Luminosity Integral Dependencies

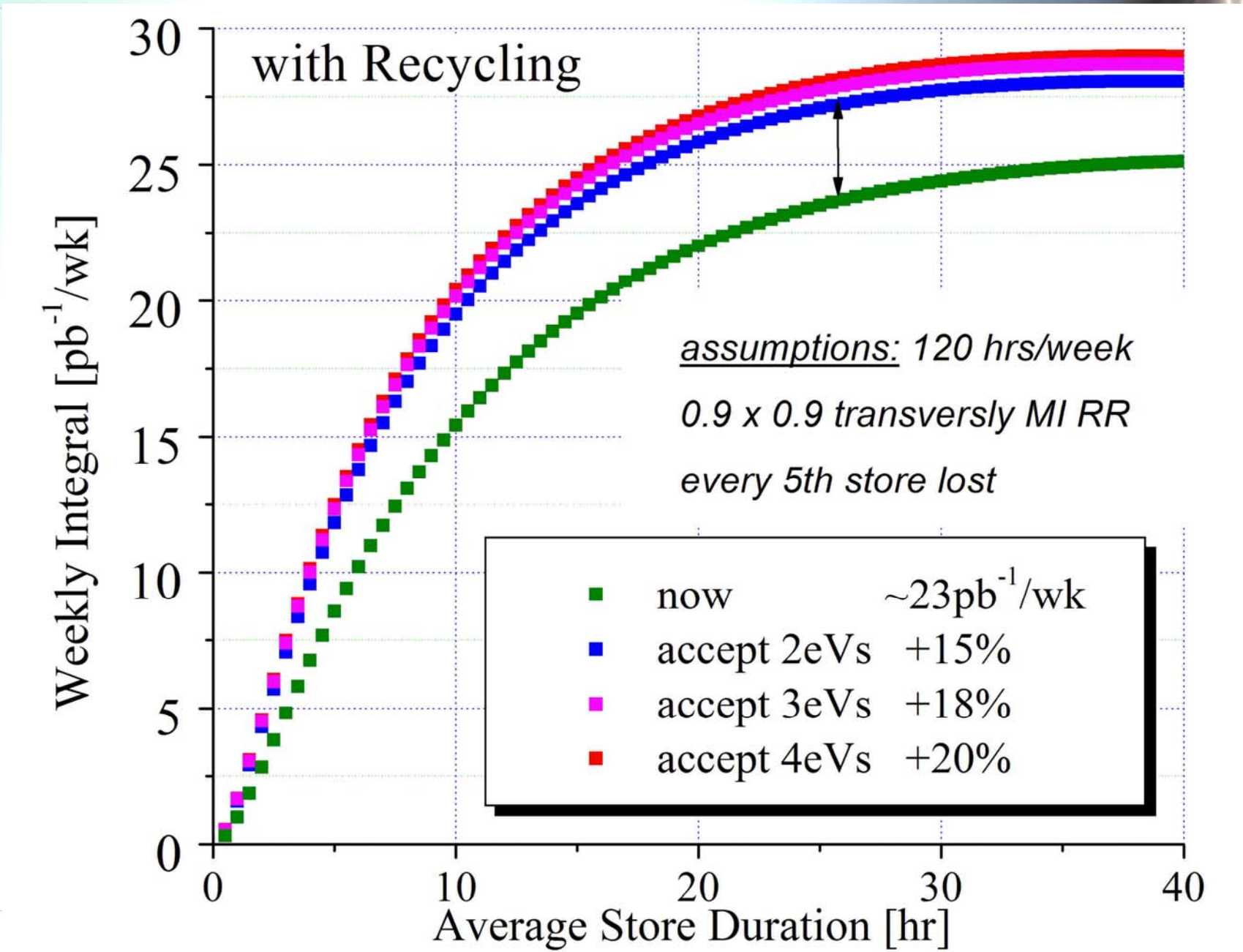
$$I = \int L dt = N_{stores} \tau_L L_0 \ln(1 + T/\tau_L)$$



Run II store lengths



Recycling gives 15-20% in Integral



20% Aperture → Production Up ~15%

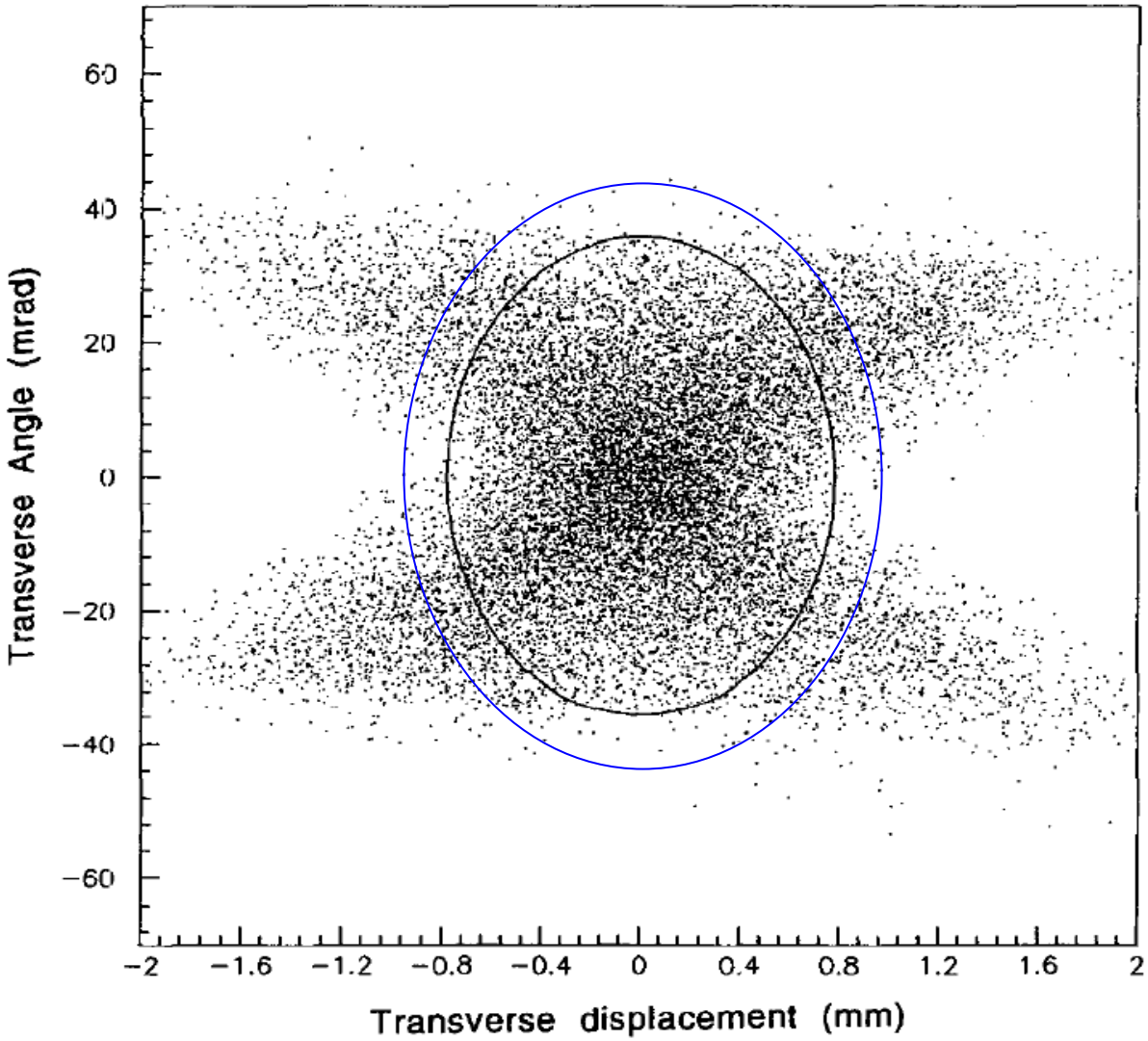
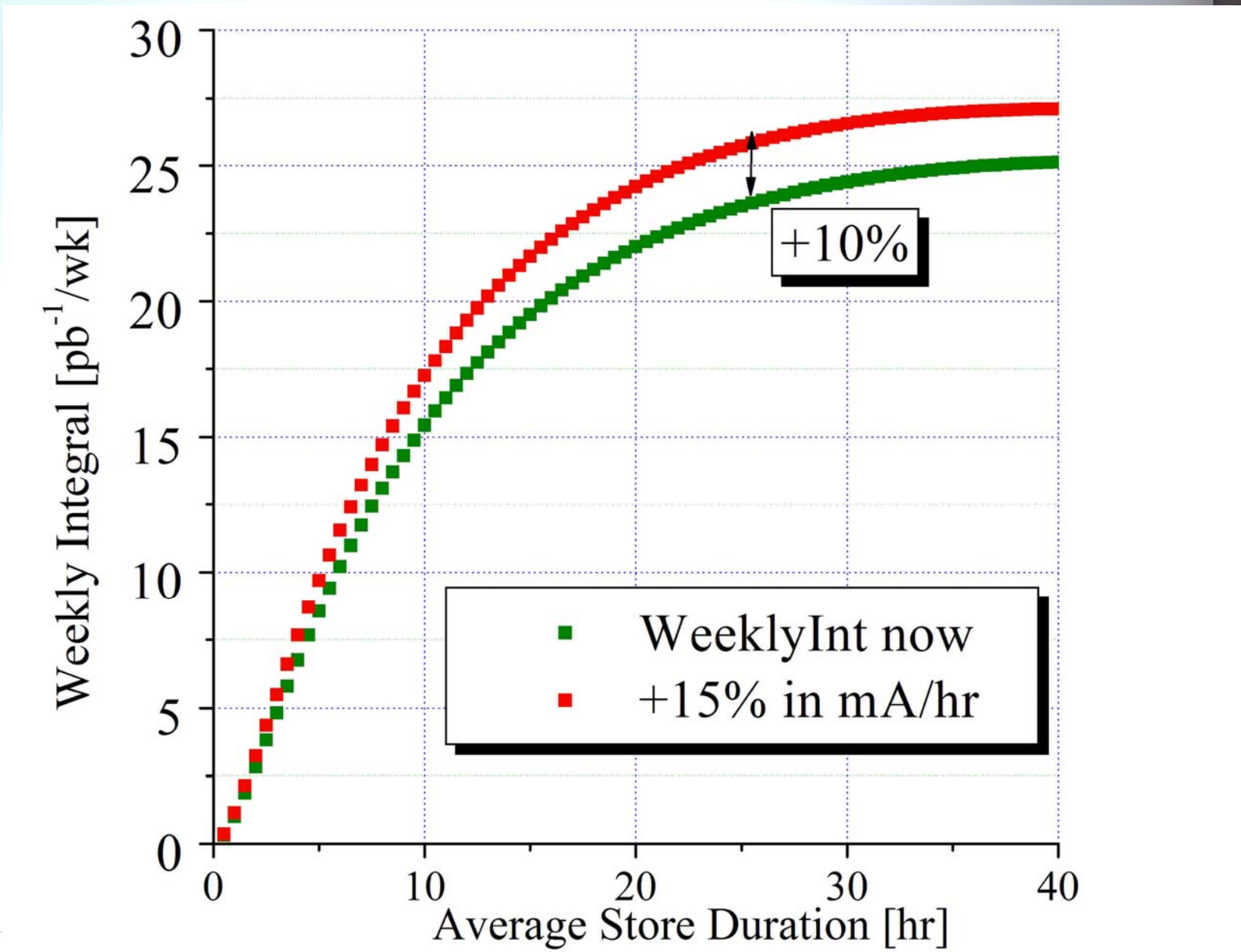


Figure 4 The phase space distribution of antiprotons at the center ($z = 0$) of the FNAL target is shown. Only the particles within the lithium lens acceptance of roughly 35 mrad are plotted. The ellipse indicates the portion of phase space that is accepted by the 28π mm-mrad acceptance FNAL debuncher ring.

M. D. Church and J. P. Marriner

Production Up 15% → 10% in Integral



Comments/Issues (1)

- **TM-1991 Recycling Efficiency estimates too optimistic:**
  - **assumed very high production rates and short stores**
- **Valery's estimates from 2002 confirmed by VS:**
  - **25-30% recycling efficiency possible for long stores**
  - **that gives 18-23% gain in peak luminosity**
  - **and 15-18% gain in integrated luminosity**
- **IBS in higher intensity pbar bunches will be about the same because of somewhat larger emittances**
- **Longitudinal emittance of 4..2eVs limits longitudinal efficiency to 0.90…0.73**
- **Transverse Emittances of about 20 pi limits transverse transfer efficiencies to ~0.8**

Comments/Issues (2)

- proton removal should be successful now (comp. to ’02)
  - 5-10 min OK , compared to 2 min before
  - better shielding at E0 and A48
  - much better control of scraper angle and position (smooth steps)
  - stabilized orbit vibrations
  - p-beam is much wider at the end of longer stores
- B2 on the ramp down and backporch
  - tested, works fine (Jerry)
- MI ramp down
  - no big problems? (Ioanis, C.Bhat)
  - 53MHz (150→25) 2.5MHz (25→8 GeV) in TM-1991
- Long and Transv apertures in transfer lines
  - critical if less than 20 pi
- Recycler was supposed to have no problem to accept 3eVs according to CDR – still true?
- Sequencer/Controls/Synchronization … is needed
- TeV IPMs may suffer … move to C0

Comments/Issues (3)

- **beam study study time needed to make r-ing operational:**
  - **realisticestimates to be given by following speakers**
  - **Valery's estimate 30 to 100 "end of stores" x1/2shift=15-50 shifts**
- **How much is too much? Examples:**
  - **10% in L-integral over next 4 years (40 wk/yr)=16 weeks=320 shifts**
  - **2 weeks of RRT studies in 2005=20 shifts →10% in L-integral**
  - **6 shifts of 28cm beta* studies in 05 → 10% and 7% in integral**
  - **8.5 shifts of 35cm beta* in '04 →30% in peak and ~20% in integral**
- **Seems that 0.5-1% of gain in integral/shift is OK → 15-30 shifts for recycling justifiable**

Comments/Issues (4)

- **(at the end) there is not much left on the table to increase luminosity :**
  - **AP2, DB, 1000 T/m Lens**
    - **20-30% in peak and 15-20% in integrated lumi** *ongoing*
  - **Tevatron new WP near ½**
    - **20-30% in peak and 15-20% in integral** *ongoing*
  - **2.5MHz pbar acceleration in MI**
    - **~6-8% in peak and 4-5% in integral**
  - **Recycling of antiprotons**
    - **15-23% in peak and 10-15% in integrated**